Analysing Pedestrian Traffic Around Public Displays

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ABSTRACT
This paper presents a powerful approach to evaluating public technologies by capturing and analysing pedestrian traffic using computer vision. This approach is highly flexible and scales better than traditional ethnographic techniques often used to evaluate technology in public spaces. This technique can be used to evaluate a wide variety of public installations and the data collected complements existing approaches. Our technique allows behavioural analysis of both interacting users and non-interacting passers-by. This gives us the tools to understand how technology changes public spaces, how passers-by approach or avoid public technologies, and how different interaction styles work in public spaces. In the paper, we apply this technique to two large public displays and a street performance. The results demonstrate how metrics such as walking speed and proximity can be used for analysis, and how this can be used to capture disruption to pedestrian traffic and passer-by approach patterns.

Categories and Subject Descriptors
H.5.m. [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous

General Terms
Human Factors.

Keywords
Public Interfaces, Performative Interaction, Behavioural Mapping, Pedestrian Traffic.

1. INTRODUCTION
Public spaces play an essential role in urban life as meeting places, areas to relax in with friends, and pathways that make up the veins of the city. William Whyte's seminal work on the social lives of small urban spaces describes what makes public spaces successful [15]. Whyte describes how everything from chairs, food, water features, street performers and sculptures influence how public squares or walkways are used in everyday life. Many of these public spaces are also becoming the homes of large displays and interactive installations, but we do not know how technology changes the way that these public spaces are used. Do non-interactive displays change the flow of traffic differently than interactive displays? How do different interaction techniques entice passers-by in public spaces? How can we gather data about people who avoid public technologies or choose not to interact? This paper aims to address these issues by tracking and analysing pedestrian traffic as an evaluation technique for public technologies.

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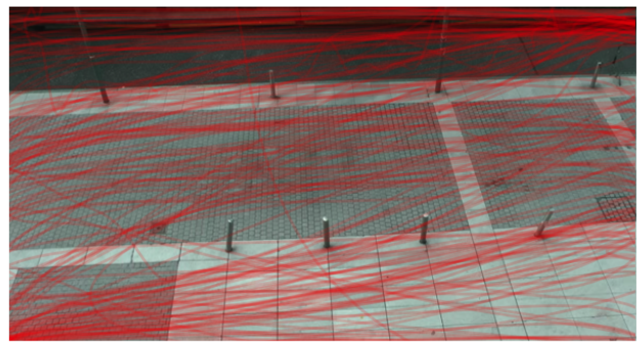

Figure 1: Each trace represents the flow of one pedestrian through the space.

Previous works in social science demonstrate how sensitive pedestrian traffic is to changes in the environment. For example, space syntax describes how social and physical attributes of space are coupled together to influence how space is used [6]. Goffman describes how different physical settings support different actions and behaviours [5]. Whyte completed extensive observational research about how different elements in public spaces change how they are used [15]. However, these previous works did not consider how technology plays a role in behaviour in public spaces. The current discourse on evaluating technology in public spaces has been more concerned with the noticeability, attractiveness, usability, and user experience of public technologies. Such evaluations focus on the technology and the people that interact with it and do not significantly consider how technology changes the space where it is deployed and how its presence affects both interacting users and non-interacting passers-by. We argue that analysing pedestrian traffic around public installations is a powerful tool that complements existing approaches that focus on interaction while also considering the wider context where technology is deployed.

In this paper, we demonstrate the utility of analysing pedestrian traffic using bird's eye views to evaluate technologies in public spaces. Figure 1 shows how our pedestrian tracker can capture and visualise undisturbed traffic in a public walkway. To demonstrate this approach, we developed the pedestrian tracker software and a suite of analysis tools that are available as an open source project. This includes all of the data sets used in this paper. The main strengths of this approach are:

- A technology/hardware agnostic evaluation technique
- Easy to add to or supplement with existing approaches
- Captures both interaction and non-interaction
- Unobtrusive data collection
- High density data generation
- Scalable data collection

2. RELATED WORK

2.1 Behaviour in Public Spaces

Previous work in understanding behaviour in public spaces has primary revolved around three perspectives: observing social and group behaviour [15], analysing the relationship between spatial and social factors [6], and understanding individuals and their perceptions of themselves in public spaces [5].

When William Whyte started researching social life in urban areas for The Street Life Project in 1971, he set out to understand why some public spaces "work" while others do not [15]. Why are some public squares empty while others are bustling hubs of activity? His approach was to study and evaluate where people spent time in public spaces and to understand the behaviour of large groups of people. He found that there were clear reasons for differences in the popularity and appeal of public spaces, such as the presence of seating areas, sunlight, greenery, water features, and position relative to the street. Whyte's approach to evaluating public spaces involved time lapse images of bird's eye views of public spaces and generating behavioural maps. This serves as the main inspiration for the pedestrian tracker tool presented in this paper.

The complex relationship between spaces and the social factors that have both influenced and been influenced by these spaces has led to the development of Space Syntax [6]. This approach gives analytical power to the social-spatial aspects of spaces by describing the links between spaces and calculating metrics that describe the relative integration of these spaces. For example, the main living spaces of homes tend to be highly accessible and well integrated into the floor layout, which can be quantified with space syntax. Although space syntax is often focused on indoor built environments, exploring how outdoor spaces work with respect to links with other spaces, entrances/exits, and integration can provide a greater understanding of how the space is used.

Goffman describes behaviour in public spaces as a "performance" of self [5], focusing on the individual to understand behaviour. This performative perspective uses dramaturgical metaphors to describe the world, where individuals become performers, observers become the audience, and places become stages. Thus all behaviour in public spaces can be considered a performance of some kind, where individuals are constantly adjusting their performance based on the feedback of others. Goffman also describes how different settings or stages can facilitate different performances. This perspective motivates our interest in studying behaviour around public technologies because such installations change public spaces and create a different "performance space."

2.2 Public and Performative Interaction

Placing technologies in public spaces not only changes those spaces, but the public setting also influences the technology. Kuikkaniemi discusses how large displays in public spaces can transform the space around the display into a stage [8]. Reeves et al. explore the role of spectators in interaction, discussing how the visibility of manipulations and the resulting effects influences the spectator experience [11]. In such public settings, designers be aware of the "performative" nature of the interaction they create, but they can also exploit performative dynamics to create novel and powerful experiences. For example, Benford et al. present how discomfort can be utilised in interaction in front of crowds [2]. Sheridan et al. use a performative interface to explore "wittingness" in performance as users explore the performative interface, are encouraged by others, and learn to interact [12].

Interaction in public spaces has also led to the development of a variety of novel technologies and interactions aimed at these settings. For example, Ten Koppel et al. describe Chained Displays, a novel display configuration that allows for multiple shapes and form factors [13]. Chained displays can be put into different configurations, such as hexagonal (displays facing outwards), flat along a wall, and a concave semi-circle. These different configurations led to different approach styles, afforded different spaces for crowding and spectating, and supported different numbers of simultaneous interacting users. Touch-based interaction has also been used in public spaces with large displays. Jacucci et al. describe the Worlds of Information system, a wall of large displays that support multitouch interaction [7]. Such technologies create new opportunities for interaction, creating performers, stages, and audiences in public spaces.

2.3 Evaluating Technology in Public Spaces

Evaluating technology and interaction outside of the lab in real world public spaces requires specific metrics and techniques. Alt et al. describe seven key research questions for evaluating public displays: audience behaviour, user experience, user acceptance, user performance, display effectiveness, privacy, and social impact [1]. These research questions can be used to inform design through ethnography and interviewing and to evaluate prototypes through lab studies, field studies, and deployment-based research [1].

A major challenge in evaluating public technologies is actually getting users to notice interactive technologies and enticing them to interact. Previous work has described the Honeypot Effect, where users are more likely to interact if other users are already interacting [3]. But how do you entice users in the first place? Walter et al. completed a field study that explored how large displays could show passers-by how to interact with gestures using a variety of prompts [14]. For example, should such prompts be integrated into the display or be shown across the entire display for short intervals? What kind of text or animations are most successful at enticing users to interact? Kukka et al. looked at how different visual qualities such as colour versus grey scale and animated versus static content could either encourage or discourage passers-by to approach a touch sensitive display [9]. Peltonen et al. completed an study on a public walkway with a touch sensitive display [10]. Their system, called the CityWall, supported multitouch interaction with Flickr content. The results describe how people used the display together and manage conflicts in the shared space.

3. ANALYSING PEDESTRIAN TRAFFIC

Understanding how technology changes the flow of pedestrian traffic in public spaces has important implications for how these technologies should designed and deployed. For example, where are users likely to gather around large touch sensitive displays? How do passers-by approach public installations to interact? When do passers-by avoid public displays and how much space do they need? This paper presents a pedestrian tracking tool and suite of analysis techniques that can be used to evaluate these issues.

This technique is highly flexible and can be used for a wide variety of evaluations. The approach scales easily to different physical spaces and footfall levels, and produces rich, dense data which can reveal fine-grained insights into pedestrian behavior. The evaluation technique is technology/hardware agnostic since cameras are simply placed above the installation. These cameras can gather video data on any installation type where meaningful observations could be made using a bird's eye view. Such cameras unobtrusively collect continuous data during installations as compared to traditional observational techniques that may interfere with staging. Because the cameras work independently of the installation, it is also simple to add this to existing evaluation techniques such as interaction logs or on device experience sampling. One of the unique aspects of this approach is that it captures, without bias, both interacting users and non-interacting passers-by. The data collected has high spatial and temporal accuracy, capturing direction, speed, and location of each pedestrian. Finally, the approach supports collecting large amounts of data not typically feasible using traditional ethnographic approaches. While traditional techniques are typically used to collect data from tens of users, this approach easily scales to hundreds or thousands of users.

In order to showcase this approach, we completed a field study of two public installations and a staged street performance and analysed the pedestrian traffic. This involved one interactive, one non-interactive installation using a large multitouch display, and a street musician's performance. We deployed the display conditions for two hours in a public walkway and the street performance for one hour with a camera mounted above the installation space. We also collected two hours of baseline data, with one hour in the morning and one hour in the afternoon, in the walkway to understand existing flows of traffic through the space.

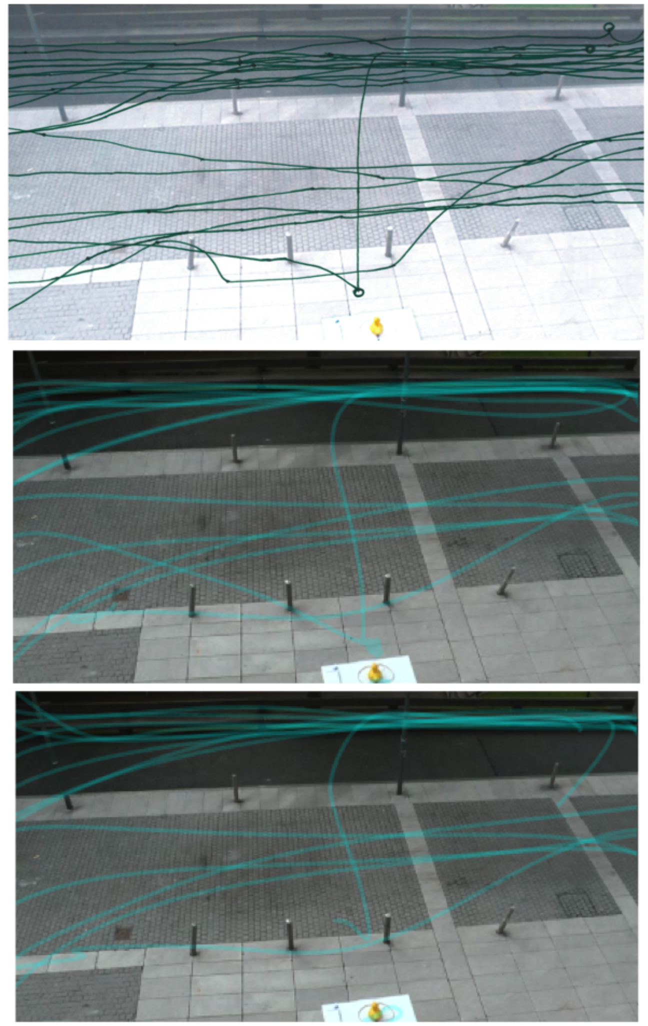

Figure 2: We validated the pedestrian tracker using four randomly selected five minute segments of data. Top: Manually generated pedestrian traces drawn by hand. Middle: Automatically generated traces from background subtraction technique. Bottom: Automatically generated traces from motion detection technique.

3.1 The Pedestrian Tracker

In order to support the evaluation and analysis of pedestrian traffic in public spaces, we developed a computer vision based pedestrian tracker tool, which includes a variety of diagnostic and visualisation tools. This tool and all the data presented in this paper are available as an open source project[1].

3.1.1 Capturing Data: Tracker Tool

The pedestrian tracker was developed based on work by Yan et al. [16] using video data from a camera mounted above the installation space. The tool supports pedestrian tracking using motion detection and background subtraction. For the motion detection technique, each frame is compared to a running window of the accumulation of the previous frames. The difference isolates pedestrians based on their movement compared to the accumulated image, representing each pedestrian as a blob in the image. Background subtraction gives better accuracy than motion detection, but is not suitable for conditions with significant variability in lighting, as is common in outdoor settings. Motion detection is much more flexible in variable lighting conditions but has a lower accuracy since very stationary pedestrians may be ignored. All the visualisations generated in this paper use the movement detection technique, as a consequence of the outdoor setting and changing lighting conditions in our deployments.

Once pedestrians are isolated using one of these techniques, they must be tracked frame to frame and given a unique identifier that remains consistent while they are visible. Our tracker implements the Hungarian Algorithm to follow each pedestrian blob across frames [16]. This is achieved by maintaining a collection of "virtual pedestrian blobs" that correspond to the observed blobs in each frame. Between each frame, the collection of virtual blobs from the previous frame is compared to the observed blobs in the current frame. A distance matrix between these blobs is generated and the Hungarian algorithm is used to match the previous blobs to a position in the current frame. Thus, each pedestrian blob is tracked frame to frame, generating a trail that captures location (centred on the

[1]More Information:http://juliericowilliamson.com/PedestrianTracking/.

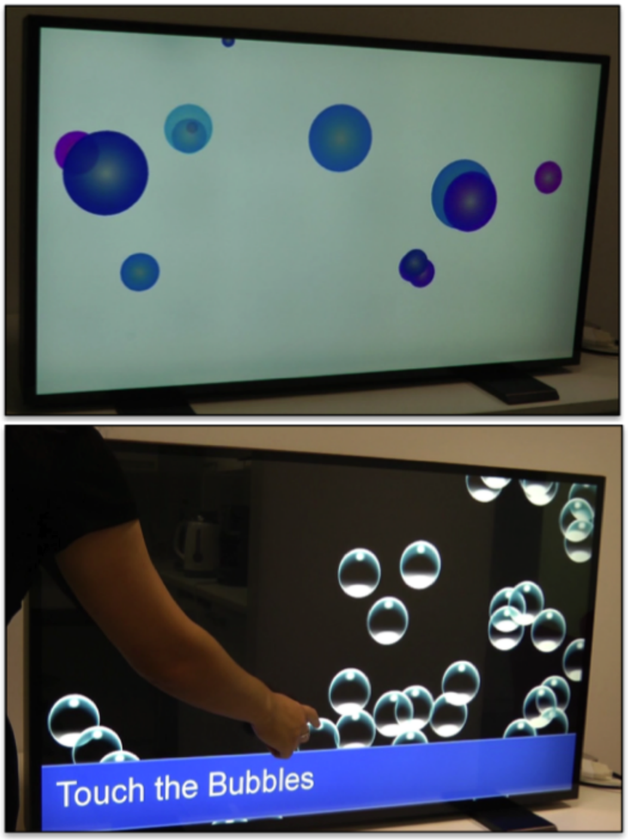

Figure 3: Top: LostInWaves is a non-interactive installation on a large display. Bottom: BubblePop is a touch sensitive installation on a large display.

individual's torso), speed, and direction of movement.

3.1.2 Validation

To validate the accuracy of the pedestrian tracker, we manually generated hand drawn pedestrian traffic maps for four 5 minute long video segments randomly selected from our dataset. Figure 2 shows the validation process for one of the five minute segments using the motion detection technique. The pedestrian tracker successfully tracks 68% of all pedestrians, where a successful track is any track where a single pedestrian produces a single continuous trail for the duration of their visibility in the frame. Each successful track captures high precision temporal and spatial data. The majority of false negatives within the data set are due to groups of pedestrians being tracked as a single track. Groups of two or three pedestrians mistakenly tracked as a single track account for 44% of false negative traces (14% of all observed pedestrians). Overall, 82% of pedestrians produce a trail representing the temporal and spatial location of either an individual or a small group walking in close proximity, which is an acceptable level of accuracy in the behavioural maps that this tool generates.

3.2 The Installations

The pedestrian tracker is demonstrated using two public installations, as shown in Figure 3. The installations were designed to demonstrate interactive versus non-interactive deployments on a 42" multitouch display[2]. The non-interactive installation shows

[2]More Information: http://www.multitaction.com/

	LostInWaves	BubblePop	Baseline1	Baseline2	Musician
Traces	241	265	170	145	114
Lower	**9%**	**8%**	35%	21%	33%
Upper	44%	41%	39%	52%	28%

Table 1: *Baseline1* and *Baseline2* are 1 hour recordings of undisturbed pedestrian traffic, while *Musician* is a 1 hour recording of a street performance in the space. *LostInWaves* and *BubblePop* are 2 hour recordings. *Lower* indicates pedestrian paths between the deployment the nearest bollards; *upper* refers to paths beyond the distant bollards.

a visualisation featuring bubble-like circles that randomly appear, expand, and disappear while shrinking. The interactive installation shows bubbles that float up the screen and pop when touched. The application is fully multitouch. This was deployed on a 42" multitouch display. The display communicates its interactive qualities using a brightly coloured bar across the bottom of the display showing the text "Touch the Bubbles." Both of the installations were purposefully simple and playful so that the pedestrian tracker could be demonstrated using a basic installation.

3.3 The Evaluation

This evaluation was completed in a public walkway that is a pedestrianised passage between two small loop roads. The camera was placed three stories above the walkway, capturing the central area of the path. Each installation was deployed for two hours, for a total of four hours of pedestrian data. That data collected also include two hours of baseline data (no intervention) and one hour of data with a street musician. For each installation, the display was placed on a table on the north eastern edge of the walkway. All of the installations were run with the experimenter present, standing behind the table. Although the presence of the experimenter may influence how the installations were used in public, this was held constant across the display conditions for consistency. The street musician condition demonstrates a different style of staging, where the musician stood alone on the south eastern end of the walkway. The experimenter was present during this condition, positioned in a seating area outside of the frame of view.

4. RESULTS

These results are based on four hours of installation video data, two hours of baseline data (video taken without any active installations), and one hour of street musician data for comparisons. The data collected describes each pedestrian with rich spatial and temporal information, with data from over 900 pedestrians. Table 1 summarises the results.

4.1 Disrupting Flows of Traffic

Small changes in an urban environment can significantly change how people use and move through that space. By capturing and analysing pedestrian traffic, we can gain an understanding of how technology changes the public spaces where it is deployed. For example, in our installation space there is a clear flow of traffic between each set of bollards on the walkway. When the traffic is undisturbed on the walkway, 35% of all traffic moves through this channel. However, when we place a display along this flow of traffic only 8/9% of pedestrians move through this channel for the interactive/non-interactive display, respectively. The street musician condition also disrupted pedestrian traffic, where 28% of pedestrians walked in the channel of traffic near the musician as compared to 39% undisturbed.

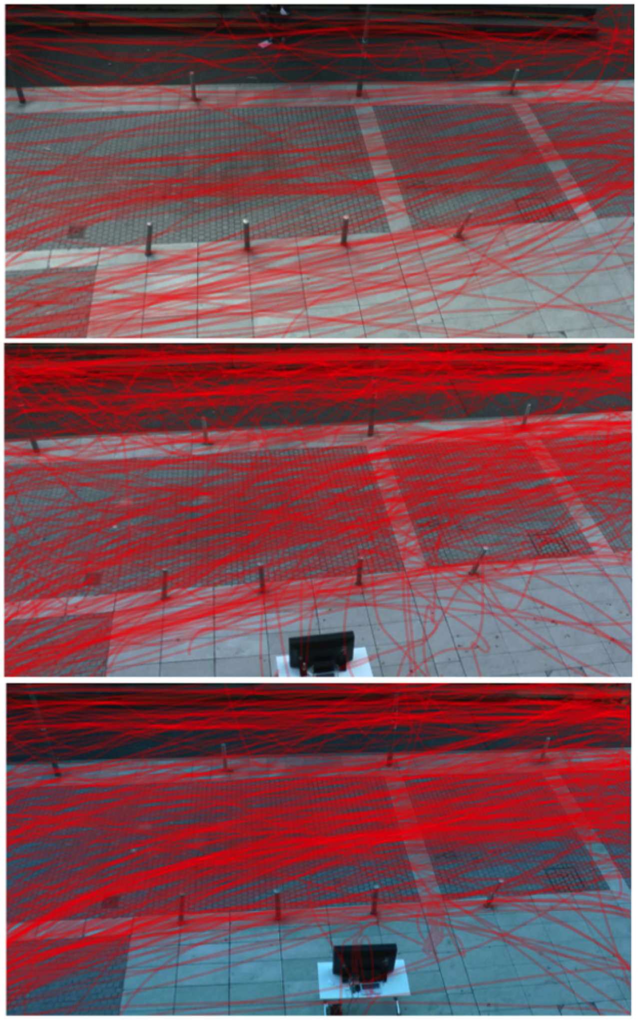

Figure 4: Visualisations of pedestrian traffic for all passers-by. Top: Street musician. Middle: Non-interactive display (LostInWaves). Bottom: Interactive Display (BubblePop).

Analysing flows of pedestrian traffic in this way can help us understand how technology changes public spaces and gain insight into how we should deploy these technologies for maximum positive impact. Examining baseline data can provide valuable insight to the placement and staging of public installations. Should the installation be placed in the middle of a flow of traffic? Should the display be placed out of the way, and along a flow of traffic? This analysis also captures non-interacting passers-by and incorporates their non-interaction into analysis.

4.2 Approaching Public Displays

An important aspect of evaluating public displays is looking at how people approach public displays. The pedestrian tracking tool can identify users that approach the display and visualise their individual pathways. For example, Figure 5 shows how the tool can isolate pedestrians that approach the display and analyse the curvature of their pathways. Figure 5 top shows passers-by that changed direction in order to approach the display, and Figure 5 bottom shows passers-by that approached the display because it was close within their direction of travel. These two kinds of interacting users represent two ways of enticing passers-by: chance enticement by happening to pass close by the display or active enticement that causes a change in direction towards the display.

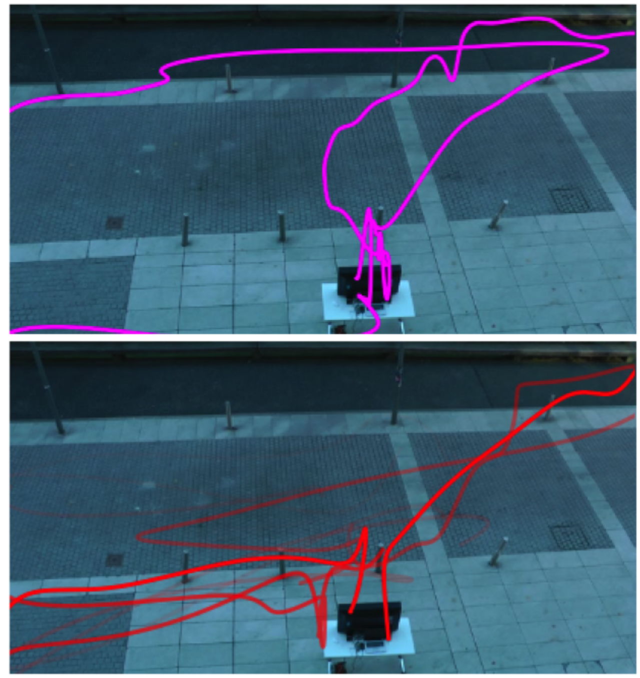

Figure 5: Visualisations of pedestrians that approached the display. Top: Pedestrians actively change direction to approach the display. Bottom: Pedestrian approach the display because it falls along their path.

Different on-display features work to convert different numbers of passers-by to interacting users. For example, using on screen prompts [14] or different visual qualities such as colour versus grey scale and animated versus static content [9]. Analysing pedestrian traffic can quantify these differences for a large number of pedestrians automatically, provides detailed information about how people approach, and could serve as a powerful tool for A-B style testing.

4.3 Moving Through Public Spaces

The pedestrian tracking tool can analyse a variety of metrics from the data such as direction of travel, speed of walking, and proximity to the display. Groups of pedestrians can be isolated and visualised based on any of these metrics. For example, Figure 6 shows how pedestrians walking within a certain proximity to the display can be identified and visualised. In this case, we can analyse what percentage of total traffic occurs within certain regions, specifically exploring how much our public display disrupts traffic and how many pedestrians are effectively “pushed back” by the presence of the technology.

5. DISCUSSION

This approach is motivated by the lack of tools to evaluate public displays in a wider context. This is a key issue that the public display community needs to consider. Our technique allows us to gather data from both interacting users and non-interacting passers-by. Analysing non-use and avoidance help us critically reflect on the negative impacts of technology on urban living. For example, public displays are often designed to be as noticeable and enticing as possible but this may negatively impact on the perceived quality of public spaces. The effect of different enticements can be analysed through how people flow around these displays.

Figure 6: Pedestrians in close proximity to the display can be isolated for detailed analysis.

Staging is an important element of public deployments. For the deployments in this paper, an experimenter was present to monitor the installation. Public installations are often curated in this way, but can also be unmonitored. The experimenter's presence changes the way the installation is staged, but the impact is not always clear. Using cameras mounted above the installation space, an experimenter does not need to be physically present. Pedestrian traffic analysis can reveal and objectively quantify differences in curated experiences and non-curated experiences.

This technique can be widely applied as it is largely independent of the display deployment and integrates easily with other methodologies. For example, pedestrian data can be used to evaluate conversion rates in a meaningful way, understanding not only how many passers-by interact but also their manner of approach. Previous works have evaluated these conversion rates by focusing on interaction logs, for example conversion from initial touch input to meaningful interaction [9] and conversion from on-screen presence to performing specific inputs [14]. Analysing pedestrian traffic supplements such detailed interaction data by describing the steps leading up to those interactions and provides a more detailed context to on-device interaction logs. Observational data can give a wider context to quantitative results of the pedestrian traffic analysis. For example, curiosity induced changes in walking speed could be confirmed and visualised using the pedestrian traces. Many qualitative analysis techniques depend on such triangulation, and the pedestrian traces can support such data.

6. CONCLUSION

We have shown that pedestrian traffic analysis is a viable and widely applicable tool for evaluating public displays. The data is collected unobtrusively and can easily be combined with existing approaches. The dense data collected provides otherwise difficult to obtain insights into interaction and non-interaction. Traffic flow analysis is highly scalable, and we were able to track almost a thousand participants in a relatively brief deployment. Our field study demonstrates the utility of our approach, and our results clearly demonstrate the impact of interactive displays on pedestrian motion. This field study showcases the technique and demonstrates the potential in automatic pedestrian traffic analysis. Pedestrian traffic analysis is an essential tool in the belt of anyone evaluating public displays; this paper only scratches the surface of the possibilities.

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